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SURVEY OF ANALYSES OF COMBAT DATA FOR U.S. ARMY AIRCRAFT IN SOUTHEAST ASIA

James R. Lindenmuth

Falcon Research and Development Company

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ABSTRACT

The U. S. Army has sponsored a long-range program to collect and analyze data on aircraft damaged by ground fire in Vietnam. This effort, sustained by contributions from many agencies and teams, culminated in a vast data bank of information concerning U. S. rotary- and fixed-wing aircraft in combat, the reactions of these aircraft and their systems to ground fire, and the resulting casualties and fatalities.

This report surveys the entire program, the analyses performed on the data, the lessons learned from these analyses, and the various payoffs in terms of survivability improvements to both fielded and future aircraft. Recommendations are offered for additional analyses to more fully exploit the data bank.

FOREWORD

This report summarizes the accomplishments of the U. S. Army Materiel Systems Analysis Agency (USAMSAA) for the period 1962 through 1973 in the collection and analysis of combat damage data on U. S. Army aircraft in Southeast Asia. The summary was done by the Falcon Research and Development Company, Baltimore, Maryland, sponsored by the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME). Special acknowledgement is deserving to Mr. James H. Young, Mr. Donald Malick, Mr. Raymond M. Malcomin, and Dr. Robert F. Bennett of Falcon Research and Development Company. The effort of summarizing the data for this report was begun in March 1973 and completed in December 1973.

The technical direction for this work was provided by Mr. James R. Lindenmuth of USAMSAA.

A more detailed confidential report entitled *U. S. Army Aircraft Combat Damage (1963-1973)* is also being published on this subject.

EXECUTIVE SUMMARY

1. Formal study of aircraft vulnerability began at Aberdeen Proving Ground shortly after World War I, primarily for the purpose of improving munitions used against aircraft. In 1962, Army Materiel Command (AMC) initiated the first research and development (R&D) program specifically designed to reduce vulnerability and improve survivability of aircraft and aircrews. Tasks were initially distributed to Air Mobility Research and Development Laboratory (AMRDL), Ballistic Research Laboratories (BRL), Army Materiel and Mechanic Research Center (AMMRC), and Natick Laboratories. Shortly thereafter, with the outbreak of hostilities in the Republic of Vietnam (RVN), BRL/AMSAA assumed the task of collecting and analyzing aircraft combat damage and loss data. The primary purpose of this effort was to identify and document causes of losses, crashes, forced landings, mission aborts, and personnel casualties in order to supplement and to challenge proving ground test results, engineering analyses, and predictive techniques.

2. The approach called for the collection and collation of data from all existing available sources, including associated operations data (flying hours, sorties, etc). By 1971, when the sources of data essentially *dried-up*, this effort had accumulated the largest single data bank of its kind. Data were collected primarily on Army aircraft with some data on USAF, USN, and USMC helicopters and light aircraft.

3. Approximately 35 percent of the collected data has now been analyzed and published in more than 30 reports. In addition, many special studies were undertaken with the processed and raw data in response to project managers, other Department of the Army (DA) and Department of Defense (DOD) agencies, and the aircraft industry. In this report the status of data collection, data analyses, and reports-in-publication is summarized; some of the accomplishments and their impact upon aircraft survivability issues are reviewed; and potential benefits of further exploitation of the data bank are suggested.

4. The collected data cover helicopters of all types and the Army fixed-wing aircraft flown in RVN: CH-21, UH-34, UH-1B/C/D/E/F/H, CH-46, CH-47, CH-37, CH-54, OH-13, OH-23, OH-6A, OH-58, H-43, H-3, H-53, AH-1G, OV-1, CV-2B, O-1, and a few others manufactured by Bell, Boeing-Vertol, Sikorsky, Hughes, Kaman, Hiller, Grumman, DeHaviland, and Cessna. Many of these aircraft were designed before 1962, prior to the time of significant vulnerability studies or combat damage data analyses, and hence were designed without benefit of essential survivability design requirements. The numbers of losses and other adverse reactions for these aircraft in the early 1960's are not surprising. However, some significant survivability design features soon began to appear, and more important, survivability design principles began to evolve.

5. The primary threat to the operation of these aircraft in RVN was the small-arms bullet, but a significant number of incidents documented the enemy's use of .50 caliber (12.7mm) bullets and explosive devices, such as rocket propelled grenades (RPG), mines, booby traps, etc. Some aircraft were lost from single hits by 7.62mm bullets on any one of a variety of critical components and systems, while other aircraft survived barrages of small projectiles or fragments and even direct hits by large RPG's. The combat data serve to document, classify, and establish the nature of aircraft reactions to a large variety of aircraft damage under a variety of flight conditions.

6. In many instances during the 10 years of data collection, the available results were used to design and justify retrofits for improving survivability. Examples of such retrofits include:

- Lightweight armor for crew and components
- Self-sealing fuel and oil tanks and lines
- Oil cooler bypass

- Void filler plastic foam for fuel fire protection in flight
- Crashworthy fuel systems

In many cases, it was also possible to use the combat data to directly measure the payoff for such improvements. It is known that hundreds of lives were saved by armor alone. It is more difficult to estimate exactly how many aircraft were saved. However, millions of dollars have been saved in OH-6's and AH-1G's alone as a result of various improvements – certainly many times the cost of combat damage data efforts.

7. More important, combat data analyses have demonstrated the feasibility of, benefits from, and the need for numerous design features for survivability, such as:

- Suction fuel pumps
- In-flight fire prevention techniques
- Dual flight controls and dual pilots
- Redundant hydraulic systems
- Multiple engines
- Oil-starvation-tolerant transmission bearings and gears
- Large-diameter hollow drive shafts
- Ballistically tolerant components
- Multiload-path structure
- Improved rotor blades

To establish survivability design discipline, requirements reflecting these design features have been defined for the new Army aircraft such as the Utility Tactical Transport Aircraft System (UTTAS), the Heavy Lift Helicopter (HLH), and the Advanced Attack Helicopter (AAH). Industry is responding to this challenge with many innovative solutions to the fundamental problems identified. Combat damage findings may also influence the development of basic required operational capability (ROC) for future aircraft such as the Aerial Reconnaissance Helicopter (ARH). In general, findings have confirmed current vulnerability prediction techniques and will lead to improved methodology and test data.

8. Many problem areas still exist requiring further exploitation of combat data analysis, the areas which appear to have large potential payoff are:

- Further analysis of AH-1G data for the AAH
- Further analysis of the CH-47 and CH-54 data for the HLH
- Further analysis of the CH-46 and UH-1D/H data for UTTAS
- Further analysis of the OV-1 data
- Comparative study (between aircraft) of damage effects to functional aircraft subsystems

- Further investigation of mission abort causes and circumstances

- Repairability and repair time

- Safety implications (to prevent accidents)

9. The total impact of combat damage data on Army aviation has been widespread and significant. In key decisions, combat data carry more weight than related mathematical or engineering analysis. Combat damage data supplement and challenge test data results; test data may, however, be obtained more systematically, efficiently, and economically.

10. Analysis of the available unprocessed data should be continued at an orderly pace to support development of the next generation of Army aircraft. In addition, the present hit-or-miss data collection approach should be improved. A well-organized system should be established for immediate deployment of specially trained teams whenever opportunities present themselves to collect data in the future.

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SECTION I — INTRODUCTION

1-1. Since World War II, tests of damage mechanism performance against aircraft have been conducted at Aberdeen Proving Ground and other locations. The collection and analysis of information concerning the reactions of manned aircraft when struck by live ammunition have long been recognized as a desirable supplement to these test data. Combat damage data provide the only source of this information. The exposure of U. S. Army aircraft to ground fire in the Vietnam conflict early in the 1960's provided the opportunity to collect a large quantity and variety of such data on aircraft damage. In July 1962, a team of analysts with experience in the study of aircraft vulnerability was sent to Vietnam by the Advanced Research Projects Agency (ARPA) for the purpose of determining how armor should be used to protect crews of Army aircraft. The resulting field experience led to a program for the collection and detailed analysis of combat damage data for Army aircraft later the same year at the Ballistic Research Laboratories (BRL), Aberdeen Proving Ground, Maryland. Under this program, data collected in Vietnam were sent to Aberdeen Proving Ground for processing and analysis. In 1968, when the Army Materiel Systems Analysis Agency (AMSAA) was formed from the BRL, the responsibility for the collection and analysis of these combat data was vested in AMSAA. To date, this program has resulted in the publication of over 30 analyses of combat damage to aircraft or of casualties to airborne personnel. BRL, AMSAA, and the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME) have all participated in the publication of these reports. In addition to these formal publications, the findings of the combat damage analyses have provided impetus for a number of related research efforts and published reports. The data base established as a result of the collection program has also been used to provide the answers to numerous requests for specific combat damage data or insights into aircraft vulnerability problems, aircraft survivability considerations, and aircraft operations in combat environments. Furthermore, this data base is available for future exploitation beyond the scope of the analyses summarized in this document.

1-2. This report summarizes the results to the present time of the aircraft combat damage data collection and analysis effort. The primary lessons learned and several applications of the data analyses are presented. Recommendations are made concerning further analyses and future applications of the existent data. The main body of the report consists of nine sections which discuss the background, the extent, and the various applications of the aircraft combat damage data analyses and give recommendations for specific areas of future analysis and applications of the combat damage data.

1-3. A special effort was made to keep the information in this report unclassified. A companion report entitled *U. S. Army Aircraft Combat Damage (1962 – 1973)*, Joint Technical Coordinating Group for Munitions Effectiveness, 61 JTCG/ME-74-2 (in publication) (CONFIDENTIAL), covers the same material but provides numbers and details which require that the report take on a *confidential* classification. The companion report provides four appendixes which present the combat damage data sources, a list of published reports based on the data collected, summary tables of pertinent information from the various published reports, brief summaries of the major reports, and samples of requests for combat data or analyses of data made to AMSAA and BRL by various government agencies and private organizations. The reader is directed to the classified version, should he require the higher level of detail. The purpose of this unclassified report is to make the basic material and information concerning the aircraft combat damage data collection and findings available to a wide audience.

SECTION II — BACKGROUND DISCUSSION

2-1. The combat damage data collected during the Vietnam conflict and analyzed in the various reports referenced in this summary involve both rotary- and fixed-wing aircraft. These aircraft were largely Army operated, but some Air Force, Navy, and Marine operated helicopters and light aircraft are also included. Most of the data are for rotary-wing aircraft, since the growth of the helicopter as a versatile combat element was spurred by the Southeast Asian conflict. At the outset of the conflict, the number of helicopters lost to small-arms fire emphasized the subordinate role that aircraft survivability had played as a design criterion. Very few of the professional specialists who were in positions to influence the design and procurement of such machines had the opportunity to observe first-hand what was needed to improve survivability. Well-documented combat damage data were the only means of gaining the necessary survivability orientation for most of these specialists. A case in point concerns armoring against small caliber bullets. In 1962, bullet-stopping armor sufficiently lightweight for helicopters was not available, primarily because the need had not been recognized by the armor materials researchers and aircraft designers. When the small caliber threat materialized, retrofit tipping plate arrangements were devised and applied within a few months, and some lives were saved. Moreover, motivation was provided for the accelerated development of the lightweight, ceramic, composite armors. Within a year these were applied as seat armor and breastplates. Figure 2-1 depicts a typical armored vest worn by a crew member, while Figure 2-2 shows the armored seat in the UH 1D. An analysis of casualties from the combat data for the period from 1962 to 1970 reveals that hundreds of lives were saved by this armor (References 1 and 2)*. It should be emphasized that, had combat statistics similar to those presently at hand been available a few years prior to 1962, the need for such solutions (and probably better solutions) could have been recognized much sooner with subsequent savings in both lives and aircraft.

* *References are contained in Section X.*

2-2. Such statistics are now available and have been exploited to increase the survivability of Army aircraft in Southeast Asia. Further analysis of these statistics is needed to provide a sound combat damage statistical base for improving future aircraft survivability. In the design of new aircraft, survivability concepts must compete with safety, reliability, and maintainability concepts for weight, space, etc. Each of these technology areas has its foundation in sizable and continuously growing statistical data banks. For instance, aircraft accident statistics are unquestionably the foundation of aviation safety research. Combat data may only be collected during periods of hostility, but analyses of data should proceed on an orderly, continuing basis. More important, readiness and means to collect data should be worked out in detail prior to the outbreak of hostilities. A data collection team, familiar with the techniques and findings of the current collection system and headed by an Army officer, should be readily available for deployment into the zone of operations of any new conflict. This team would have a twofold mission: to collect combat data for analysis and to serve as a pipeline for information flowing from combat data analyses directly back to the troops actively involved in combat. This dialogue would result in lives saved, reduction of equipment losses, and improved morale. The thrust of this report relates to combat damage to aircraft, but a data collection team in a combat zone should collect combat damage data for personnel and all classes of military materiel.

2-3. The most frustrating aspect of combat damage analysis is trying to measure directly and precisely from combat statistics the benefit of a single survivability *fix*. There has never been an official reporting system in the Army (or in DOD) organized to systematically and consistently record events wherein a given survivability feature saves a life or an aircraft or a mission. This lack of adequate followup, further influenced by the premature closing down of the data-gathering system in Vietnam, precludes many dramatic demonstrations of survivability payoffs at this time. The timely completion of Ballistic Research Laboratories Memorandum Report 2030, *U. S. Army Casualties Aboard*

Figure 2-1. Aircrew armored vest.

Figure 2-2. UH-1D armored seat.

Aircraft in RVN (1962-1967), provided the information which was a principal factor in the initial decision to retrofit one of our key aircraft. This helicopter, equipped with a crashworthy fuel system, arrived in Vietnam when the combat data sources began to close down. As a result, the combat data provided under the collection program were insufficient to show the number of lives saved by the crashworthy fuel system in a combat environment. This is an example of an important fix prescribed in response to combat damage analysis for which the opportunity for evaluation was lost.

2-4. While the importance of the application of combat damage analyses to the immediate improvement of survivability of Army aircraft operating in Southeast Asia should not be underestimated, the primary lessons to be learned from these studies have major applications in the design of new aircraft and in optimizing their future employment in combat. Information concerning the potential weakness of certain systems of the aircraft employed in Vietnam suggests that aircraft proposed for future use may be made less vulnerable to hostile enemy action. Practically every component or system in an aircraft has some effect on the survivability of an aircraft in a combat zone. Information obtained from the various combat damage data analyses concerning the vulnerability of the systems and components of helicopters has been applied in the design requirements for four types of future Army helicopters; namely, UTTAS, HLH, ARH, and AAH. This application in the design stage, when changes may frequently be made very simply and at little or no extra cost, contrasts dramatically with retrofit aircraft changes, which are generally both difficult and costly to make. The use of combat damage data by the aircraft industry offers a great potential for payoff. Many aircraft companies have solicited, and have been given access to, the raw combat damage data for limited surveys on specific problems. Some of the companies which received data have reciprocated by contributing large amounts of company-collected data to the AMSAA data bank. When the designers in industry recognize, understand, and appreciate vulnerability problems, they frequently find better or more suitable solutions than might be suggested by government sources not as intimate with design problems. This is most apparent in the recent designs for UTTAS, HLH, and AAH in which industry's improvements in the survivability of candidate designs have evidenced a growing awareness by the design engineers of the importance of these considerations.

2-5. The body of data from Vietnam provides an abundance of information on the levels of damage required to constitute attrition to helicopters, to cause a forced landing, and to cause the crew to abort a mission. Further information, which may have application in analytic predictive techniques for the vulnerability and survivability of aircraft, is available and should be fully exploited.

2-6. As pointed out in Section III, the available data have not been fully analyzed or exploited. Although much of the data has been examined in detail and useful information has been generated and recorded in various reports, many additional analyses should be performed. The desirability and potential use of the information from such analyses are discussed in Section IX.

SECTION III – EXTENT OF THE AIRCRAFT COMBAT DAMAGE DATA COLLECTION AND ANALYSIS PROGRAM

3-1. The purpose of this section is to review the extent of the combat data collection and the analytical effort in order to put the entire program in perspective.

3-2. When an Army aircraft was hit by enemy ground fire in Southeast Asia, the details of the incident were documented in a combat damage report, which was then forwarded to AMSAA. Unit commanders were required to report daily every aircraft incident. These incidents were reported via the Joint Services Antiaircraft Fire Incident and Damage Report (JSIDR) and forwarded weekly to 7th Air Force. The completed forms were sent monthly to AMSAA. Additional data regarding combat damage sustained by Army aircraft were gathered from other sources. Aircraft operational data, obtained for the most part from the official form for reporting information on aircraft operations in Southeast Asia, designated as OPREP-5 by CINCPAC Instructions 003480.1, are included in the analyses of the combat damage data.

3-3. The collection of combat data concerning aircraft damaged by ground fire in Southeast Asia began in 1962 and was officially terminated on 31 December 1970, when MACV Directive 381-34 was rescinded. However, some coarse combat data continued to trickle into the bank while other sources of data remained active. These other sources were the only link with aircraft incidents after 1970 and were employed to gather data for such aircraft as the AH-1G, the OH-58, and the UH-1H. Such data were important for information applicable to future Army aircraft design.

3-4. From 1962 to 1970, almost all Army aircraft ground-fire incidents were reported to BRL or AMSAA directly or through OPREP-5. A breakdown of those incidents which have been analyzed in published reports indicates that some analyses have been made of about 35 percent of the reported aircraft incidents. Even the analyzed data should be considered for further analysis.

3-5. Thirty-one reports have been published concerning combat damage to U. S. aircraft, effectiveness of selected enemy weapons, compendia of incident and hit data, and Army casualties aboard aircraft. Of these reports, 21 relate to damage analyses for specific aircraft (16 Army and 5 non-Army). In addition to these published reports, two reports on damage to Army aircraft (OH-6A and OH-58A) and another report on Army personnel casualties aboard aircraft from 1968 through 1970 are being prepared for publication. A report covering combat damage of the Army OV-1 aircraft during the time period from July 1967 through December 1970 has been proposed.

3-6. In addition to the formal published reports, AMSAA and BRL have responded to many formal and informal requests for specific combat damage information. In some instances, the response was rapid since the data were on hand. In other instances, the response to requests required larger tasks with expenditures of man-weeks or man-months of time.

3-7. The results of several of the analyses of combat damage data have been used as the basis for establishing vulnerability reduction and survivability improvement requirements which become a part of the design specifications for follow-on Army helicopters. The findings of various combat damage data analyses have also been instrumental in either initiating or giving direction to other related research activities, such as specific test programs, analytical investigations of aircraft systems, etc. The interrelationships between aircraft combat damage data analysis, aircraft vulnerability and survivability research are difficult to characterize completely as to cause and effect. This is especially true in many cases where the same analyst is involved with both aircraft combat damage data analysis and related aircraft research.

3-8. Several vulnerability or survivability reports have been published which directly incorporate aircraft combat damage data from the AMSAA data bank for specific application to the analyses documented by these report. References 3 and 4 are examples of such reports.

SECTION IV – THREATS ENCOUNTERED

4-1. MAJOR THREATS AND INTENSITY OF WARFARE

a. One timely benefit of rapid processing of aircraft combat damage data is that quantitative information may be generated about the nature of the ground-fire threat during various time periods of combat operations. Thus, suspected changes in the type and number of threats encountered may be either confirmed or denied by analysis of these data. This real-time information is of immeasurable value in planning aerial combat operations and also in anticipating aircraft losses. These data also provide a means to forecast the effects of passive protection on aircraft which are to be used in similar combat environments.

b. During the Vietnam war, a series of computer runs was published annually to present results on hit incidents and threats. (For a complete list of these reports see References 5, 6, 7, 8, and 9.) These computer runs provided an index for all incoming data. More important, they provided a measure of what was occurring in combat with respect to the type and numbers of threats encountered. These summaries have been available for use in operational planning as well as for determining the nature of the ground-fire threat to aircraft in Vietnam.

c. With few exceptions, notably the Tet offensive of 1968 and the operations at Lam Son, the combat environment in Southeast Asia was predominantly low intensity throughout the period of involvement of U. S. forces. The principal threat faced by Army aircraft throughout the conflict was the .30 caliber (7.62mm) bullet. This ammunition was reportedly used in the large majority of the damage incidents analyzed. Caliber .50 (12.7mm) bullets accounted for a small percentage of the combat incidents.

d. As the enemy weapons inventory became larger, there were more and more instances of damage to U. S. aircraft from heavier weapons, until finally, it became feasible to prepare separate combat damage reports concerning these weapons. For example, a report (Reference 10) concerning rocket propelled grenades (RPG) presented an analysis of data on a weapon designed to kill tanks but used by the enemy against U. S. helicopters. These data may be employed to estimate the effects of weapons having warheads similar to that of Redeye, as well as the effects of 23mm and 57mm high-explosive (HE) shells. Here was an opportunity to examine the effects of weapons which would normally be heavily employed in mid-intensity warfare. Data of this nature are essential to vulnerability analysts. Another report (Reference 11) was published on damage to aircraft by other threats (mines and booby traps).

4-2. THE RPG AND THE MINES/BOOBY TRAPS REPORTS

a. The RPG report presents a detailed analysis of incidents involving a variety of rotary-wing aircraft. The incidents occurred during the period 1967 through 1970. The RPG type weapons were first identified in use by enemy forces early in 1967. Prior to that period, these weapons may have been in limited use. Although primarily designed as an antitank weapon, the RPG was employed against some helicopters, particularly when these aircraft were obliged to fly low and slow, hover, or land in order to perform their missions. Details concerning the extent to which the individual aircraft were involved in RPG incidents may be obtained from the report.

b. In a similar manner, the report on mines and booby traps (Reference 11) presents an analysis of damage to helicopters by these particular weapons. The incidents included in the report for analysis occurred during the period January 1962 through June 1970. The aircraft involved in the incidents represented a variety of rotary-wing aircraft. Most of the mines/booby traps incidents took place while the aircraft were near or on the ground. This is to be expected for weapons of this type. Therefore, it is not surprising that aircraft which, in order to perform their missions, must either land or hover, often showed the highest percentages of mines/booby traps incidents.

SECTION V – APPLICATION OF COMBAT DAMAGE ANALYSIS – AIRCRAFT SYSTEMS

5-1. INTRODUCTION

a. The aircraft combat damage analyses have been published as a series of reports, each report dealing in detail with one particular aircraft class or type. This is a logical and useful method to present such data. The data presented in these reports permit comparisons between the damage responses of different aircraft types when exposed to similar ground-fire conditions. Of particular interest is the comparison of these damage responses from a systems standpoint.

b. An aircraft is often considered as a basic airframe augmented by a number of systems. The more important of these systems are those concerned with fuel, engines, lubrication, transmission, flight controls, hydraulics, and, in the case of helicopters, the rotors. Each aircraft manufacturer employs his own staff of engineers to design these systems, and no two engineering staffs have identical design philosophies. Combat damage analyses provide a means for comparing hardware reflecting differing philosophies. These comparisons are helpful when the specifications for the next generation of aircraft are to be written. Most aircraft manufacturers conduct private combat damage analyses on their own products, and some of these analyses are well done. The combat damage analyses conducted by AMSAA cover all Army aircraft, regardless of manufacturer. Thus, the opportunity appears to make critical comparisons of design philosophies. Some examples of how such comparisons have been made and the way in which the results have influenced the specifications for future aircraft will be presented in this section.

c. Naturally, some aircraft systems are more likely than others to fail as a result of a hit, and failures of some systems result in more serious aircraft reactions than failures in others. The survivability of the aircraft demands that those systems most closely connected with the aircraft's capability for continued flight be most difficult to defeat by ground fire. Two questions immediately arise: 1) Which systems, when damaged, are most often responsible for adverse reactions? 2) If the systems are ranked according to the frequency in which their damage caused adverse reactions, does this ranking vary significantly from one aircraft type to another? The answers to these questions serve as guideposts in the specifications for new aircraft and in retrofit *fixes* to existing aircraft. A system which, when damaged, is frequently responsible for a uniformly high rate of adverse reactions, regardless of aircraft type, may be so identified and toughened in future aircraft. A system which when damaged causes a large percentage of adverse reactions in a particular aircraft type, but not in others, may be singled out for further analysis to determine the sources of the weakness.

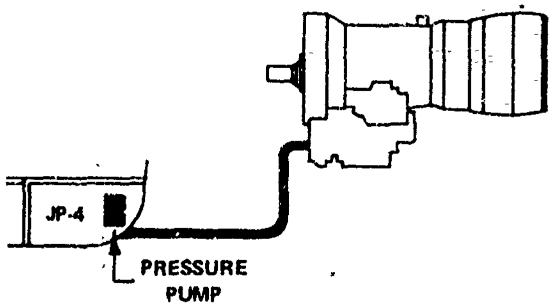
d. Systems may be selected for finer analysis with the detailed combat damage data. The engine, controls, and fuel are examples of systems which have been singled out in this way. In the subsections which follow, illustrations will be given of the types of analyses that have been performed on these systems. The illustrations will show the nature of the analysis and the value of the extracted information. Many similar analyses have yet to be made with the data presently available.

5-2. FUEL SYSTEM COMPARISON

The fuel system on two helicopters differs from that used on other helicopters in that a suction boost pump is used instead of the conventional, positive-pressure boost pump. Schematics of both types of fuel systems are provided in Figure 5-1. Because this suction boost pump represents a major departure in fuel system design, both controlled experiments and combat damage analysis were used to determine the relative merits of the two types of pumps. A fairly coarse performance criterion may be used when comparing two fundamentally different approaches to system design as in this case. The performance criterion applied to the combat damage data is the frequency of fuel fire following a fuel system hit and the severity of the adverse reaction following such fuel fires.

5-3. DUAL HYDRAULIC SYSTEMS

A second case in which it is possible to make comparisons between two fundamentally different design concerns the use of dual hydraulic systems as opposed to a single system. These designs were compared against the criterion of the number of adverse reactions occurring as a direct result of hydraulic system hits, taken as a fraction of the total number of hydraulic system hits. On the heavier aircraft,



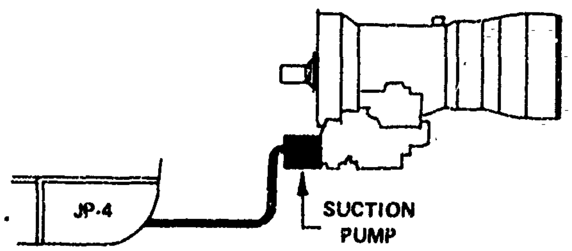


Figure 5-1. Positive pressure boost system vs suction fuel boost system.

many of the flight control functions are either fully hydraulic or have hydraulic-assist devices. In order to illustrate the relative vulnerability of a single system, the ratio of the number of crashes to the number of hits on the hydraulic system is compared for four helicopters with dual systems and for an aircraft with a single hydraulic system.

5-4. MULTIPLE-ENGINE POWER PLANTS

a. Two examples are given here of combat damage analyses which were made in order to evaluate the effectiveness of multiple-engine power plants in reducing helicopter vulnerability to small-arms threats.

b. In the first example, the survivability of the power plants on the four twin-engine helicopters used in Southeast Asia is compared with that of a single-engine power plant. The result of this comparison does not simply suggest, for example, that two engines are better than one, but rather provides a set of guidelines for determining when a second engine, designed into a helicopter, will in fact be an asset to survivability. Similar analyses, leading to application guidelines for other systems, are possible and indeed should be made with the collected combat damage data as part of continuing effort (See Section IX). It is postulated that a dual-engine power plant for an aircraft is a survivability asset, provided that either engine can supply enough power to maintain flight and that other survivability requirements are maintained. However, if the loss of either engine results in a reduction of available power below the minimum required for flight, then the second engine is regarded, from the survivability standpoint, as a liability rather than an asset.

c. The second example of a multiple-engine power plant analysis examines the degradation of the single-engine flight capabilities for armored helicopters that sustain engine damage while performing rescue missions. The analysis first compares the observed performance of the helicopter, when it has lost one engine in combat, with the predicted single-engine performance. These calculations include the effects of altitude, speed, and gross weight at the time of the hit. Once the combat damage data have been used to verify *danger zone* calculations, the calculations may in turn be used to estimate the degradation in single-engine performance which may result from the added weight of the armor. Two types of calculations are of interest here. The first involves the maximum gross weight which the helicopter can sustain in various flight phases. The second involves the conditions under which a controlled landing may be executed, despite the loss of an engine.

5-5. MAIN ROTOR BLADE VULNERABILITY

a. Another crucial area to which combat damage analysis has been applied is the verification of laboratory data concerning the vulnerability of an aircraft system or component. Such use of the combat data does not depend on making comparisons between different implementations of a given system, but rather considers all data on the system, for all aircraft types, in order to gain insight into the damage and failure modes which occur in actual combat. A particular example of this concerns the main rotor system of helicopters, specifically the main rotor blades.

b. Experiments conducted at Aberdeen Proving Ground indicate that the main rotor blades designed for most U.S.

helicopters are not easily defeated by small-arms ammunition. However, tests indicate that rotor failure may be caused by a fragmenting HE device, such as a small shell, mortar, or missile warhead, striking small blades or the spar area of large blades. The average presented areas of the main rotor blades of a helicopter represent as much as one quarter of the average presented area of the aircraft. For example, for the light observation helicopters, the average presented area of the main rotors represents 1/6 to 1/4 of the average presented area of the entire helicopter.

c. The combat damage data provide an opportunity to verify the laboratory findings concerning the vulnerability of rotor blades to various threats in actual combat situations. The ratio of hits on the rotor blades to the total number of hits on the aircraft may be used to verify the presented area estimates. The percentage of hits on the main rotor should be somewhat less than the percentage of the average presented area of the helicopter accounted for by the main rotor, if the assumption is valid that ground fire will usually be directed toward the body of the helicopter.

5-6. VOID FILLING MATERIAL AROUND FUEL CELLS

Another area in which combat damage analysis served to confirm the findings of BRL experiments concerns the ignition and sustained fire of fuel spilled into the voids between aircraft fuel cells and the aircraft skin. Proving ground experiments conducted in 1963 indicated that, if this void is large enough, an explosive mixture of fuel and air is obtained when fuel is sprayed into this space following a fuel cell hit. When an armor-piercing incendiary (API) projectile hits a fuel cell and causes fuel leakage into such voids, this explosive mixture may be ignited by the flash of the functioning incendiary round. The proving ground experiments suggested practical procedures to cope with this fire hazard from incendiary rounds. One innovative procedure recommended was the insertion of plastic foam filler in the cavities around the fuel cells. Figure 5-2 offers an explanation of how the use of plastic filler should thwart the action of incendiary projectiles. Combat damage analysis should provide the means for evaluating these procedures.

5-7. HARDWARE FEEDBACK

a. The analysis of combat damage to aircraft systems and components has often contributed to hardware changes, either by changes in design or by retrofit. A few such hardware changes and the role that combat damage analysis played in their realization will be discussed here.

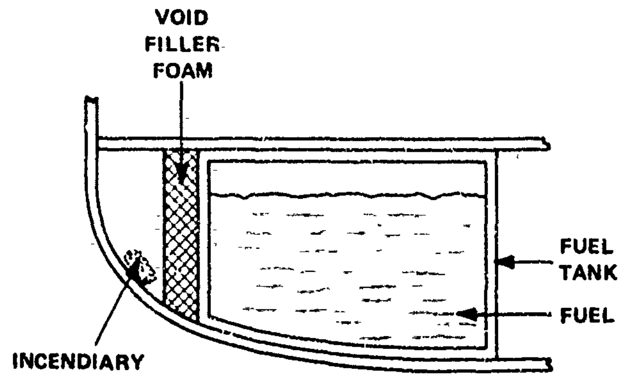
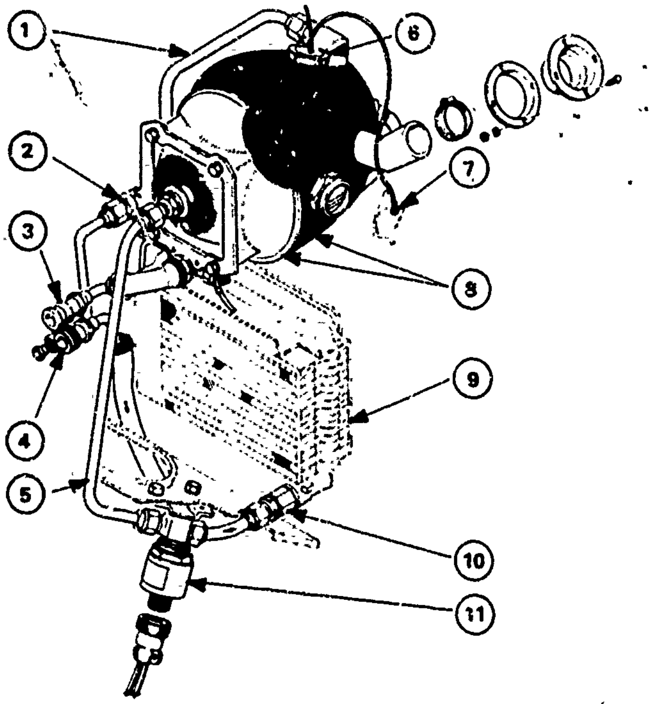


Figure 5-2. Installation of void filler plastic foam.

b. Combat damage data on one Army helicopter indicated that many adverse reactions involving damage to oil systems were caused when the oil cooler and its associated lines were perforated by bullets. The resulting loss of oil required almost immediate shutdown of the engine before the bearings seized in either the engine or transmission. Invariably, a forced landing ensued from this damage with resultant aircraft damage or loss. Both the engine and transmission contain sufficient oil for continued helicopter flight, if a means is provided for isolating these systems following a hit on the associated lines. As a result of this analysis, the engine oil system in another Army helicopter was equipped with a level sensor which was designed to detect sudden reductions in the oil supply. The transmission oil system was equipped with a similar system which was designed to detect sudden drops in oil flow rate. Figures 5-3 and 5-4 provide illustrations of oil cooler bypass features in both the oil system and the transmission of modern helicopters. The coolers were equipped with bypass valves which could, in the event of a signal from these sensors, isolate the appropriate cooler and most of its lines from the oil system. The result was that when the cooler or its lines were hit, the affected system became self-contained and uncooled. The temperature of the engine or transmission rises when this happens, but sufficient time is provided for flight to a safe landing area before further damage occurs. It appears that the oil cooler bypass systems incorporated in the engine and transmission oil systems have been responsible for reducing the number of adverse reactions.

c. A second survivability feature concerns the armoring of the control and compressor sections of the engine of some helicopters. Combat damage analysis had shown that damage to these sections caused many of the engine failures during combat flights of turbine-powered helicopters. Ceramic armoring panels were located on some helicopters so as to protect these components from ground fire.



1 OIL TANK VENT
2 ENGINE OIL VENT LINE
3 ENGINE OIL-IN HOSE AND COUPLING ASSY
4 ENGINE OIL-OUT HOSE AND COUPLING ASSY
5 OIL COOLER BYPASS LINE
6 LOW-LEVEL WARNING SWITCH
7 LOW-LEVEL SWITCH GROUND
8 SELF-SEALING OIL TANK AND MOUNTING SUPPORT CRADLE
9 OIL COOLER
10 CHECK VALVE
11 OIL COOLER BYPASS SOLENOID VALVE

Figure 5-3. OH-6 oil system with self-sealing oil tank and oil cooler bypass.

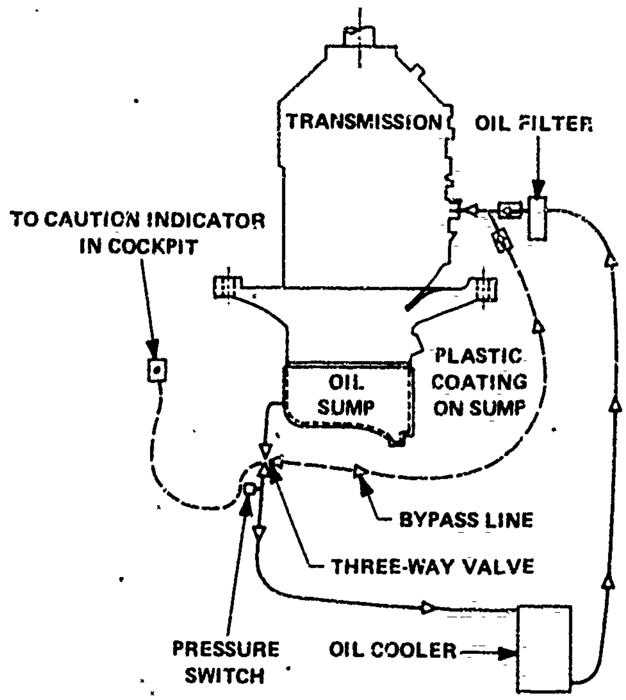


Figure 5-4. AH-1G transmission oil cooler bypass.

d. Combat damage data have been utilized to provide information on the distribution of hits on certain aircraft. Such information is used to determine the optimum disposition of armor to protect such aircraft.

e. Many changes were under consideration to reduce the vulnerability of the OH-58 to ground fire long before much combat data on that aircraft had been accumulated. In order to weight and assess the potential effects of such changes, the results of light observation helicopters (LOH) combat experience were closely examined. For example, data describing the distribution of OH-6 hits by direction and angle were used in designing armor changes to the OH-58. To further reduce the vulnerability of the OH-58, recommendations were made and implemented to use self-seal fuel and oil lines, to increase the diameter of the tail rotor drive shaft, and to fill the cavities surrounding the OH-58 fuel cells with plastic filler. Figure 5-5 illustrates three types of lines used to transmit fuel. Combat damage data analyses for the OH-13/23 had established the vulnerability of tail rotor drive shafts to small-caliber threats.

f. The high incidence of fatalities in crashes and post-crash fires has been observed in the combat damage data. As a result, crash-resistant and bullet-sealing fuel cell materials and self-closing fittings have been incorporated into a crashworthy fuel system designed for, and installed on, Army helicopters. Figures 5-6 and 5-7 illustrate the differences between a standard fuel system and a crashworthy fuel system.

g. When a design feature fails to live up to its promise, it is the responsibility of combat damage analysis to establish the extent of and the reasons for the failure for possible benefit to future aircraft designs.

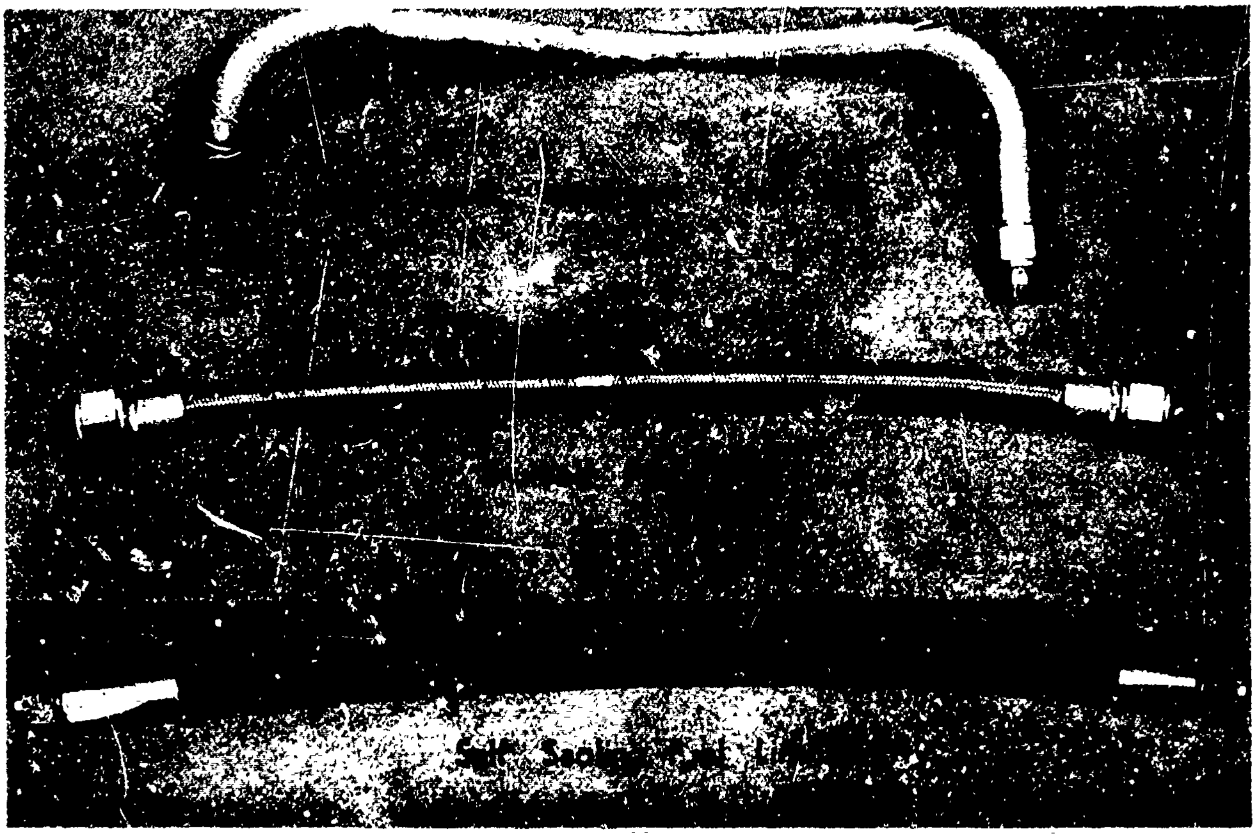
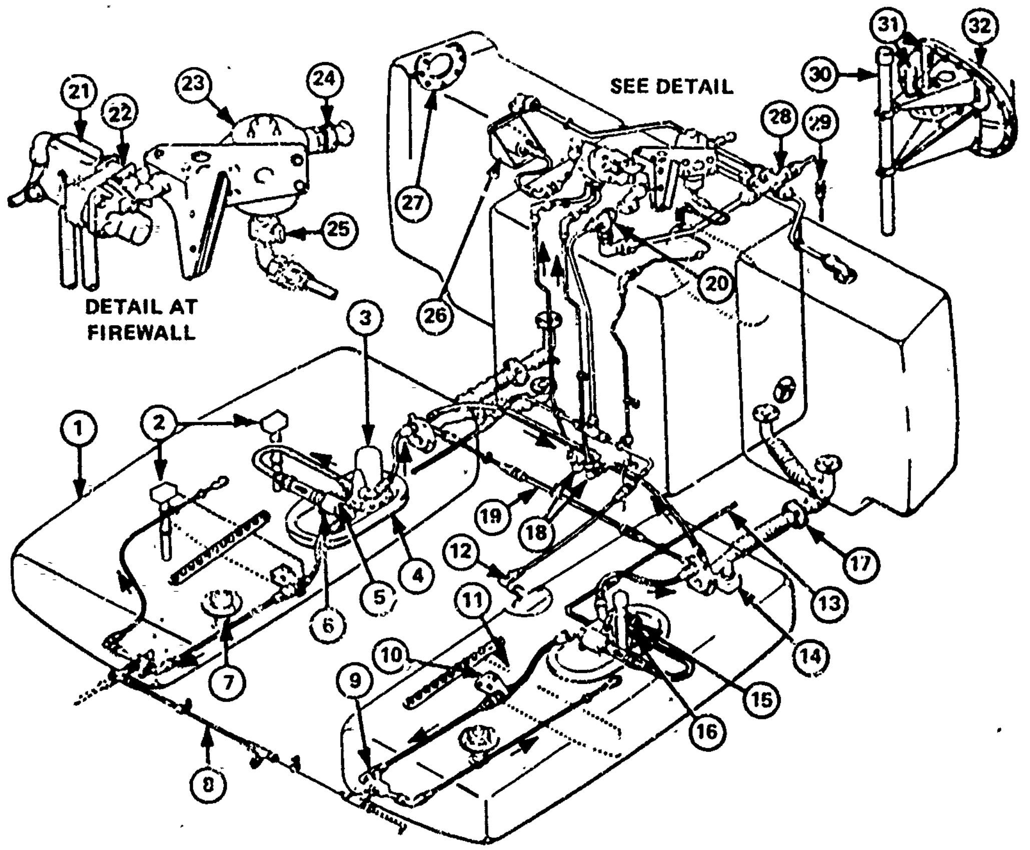


Figure 5-5. Three types of fuel lines.



1 FORWARD CELL
2 FUEL QUANTITY TRANSMITTERS
3 ELECTRIC BOOST PUMP
4 SUMP ASSEMBLY
5 FLOW SWITCH WITH CHECK VALVE
6 SUMP DRAIN VALVE
7 DRAIN VALVE
8 CROSSFEED LINE
9 EJECTOR PUMP
10 FLAPPER VALVE
11 BAFFLE
12 VENT LINE
13 BLEED AIR LINE FROM ENGINE
14 DEFUEL VALVE
15 AIR DRIVEN BOOST PUMP
16 FLOAT SWITCH
17 CROSSOVERS
18 FUEL LINES – TANKS TO VALVE MANIFOLD
19 CROSSFEED LINE
20 SIFHON BREAKER VALVE
21 CHECK VALVE MANIFOLD
22 FUEL SHUT-OFF VALVE
23 MAIN FUEL STRAINER
24 COUPLING FOR ENGINE FUEL HOSE
25 STRAINER DRAIN VALVE
26 PRESSURE GAGE TRANSMITTER
27 FILLER CAP
28 VENT MANIFOLD
29 FUEL CONTROL VENT LINE
30 FUEL QUANTITY TRANSMITTER
31 FLOAT SWITCHES – AUXILIARY FUEL TRANSFER PUMP CONTROL
32 CENTER CELL ACCESS DOOR

Figure 5-6. UH-1D/H standard fuel system.

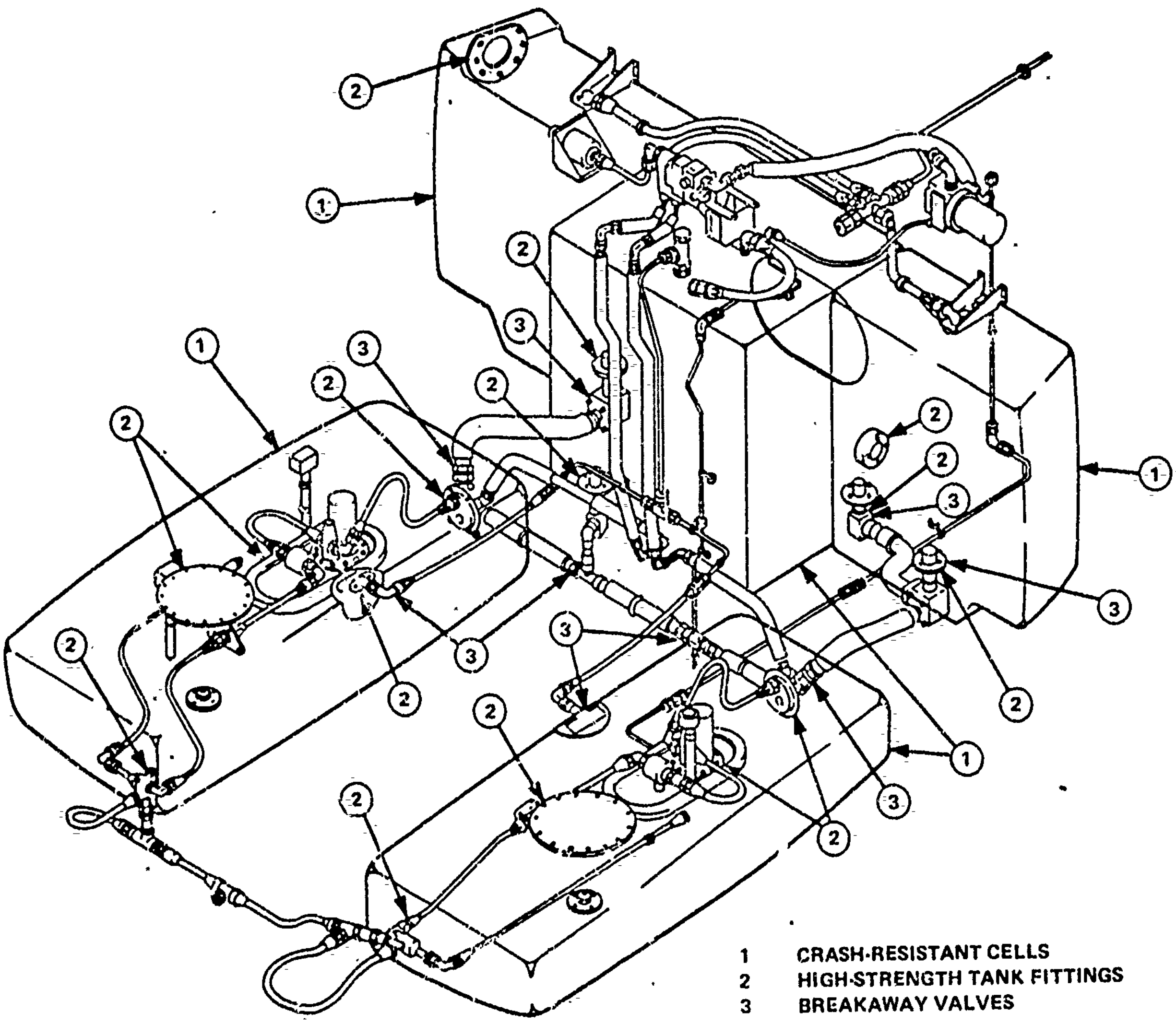


Figure 5-7. UH-1D/H crashworthy fuel system.

SECTION VI — APPLICATION OF COMBAT DAMAGE ANALYSIS — OPERATIONAL CONCEPTS

6-1. SUPPLEMENTING AIRCRAFT MANUALS

a. The results of the various aircraft combat damage data analyses and a continuation of these investigations may be used to improve the operator manuals and pilot training for future aircraft. The influence of these studies on the design requirements for improved survivability of future aircraft is discussed in other sections of this report. As these improved design features are incorporated in future aircraft, these features should be described and discussed in the manuals. Furthermore, lessons learned concerning the utilization of aircraft in combat, and in particular, concerning emergency procedures which have evolved from combat experience, should be included in the operator manuals for each aircraft.

b. Early in the Southeast Asian conflict, rotary-wing aircraft flew into combat virtually unarmored. There was no lightweight armor available for aircraft and aircrew protection. Aircrews improvised their own makeshift armor largely for their own protection, and this armor often overloaded the aircraft. As a result of many analyses of the combat damage to these aircraft, much effort has been expended to design and install effective armor for aircrews and components into many of these aircraft used in the later stages of the conflict. Many engineering hours will be devoted to armor designs to be incorporated into future aircraft. Furthermore, as aircraft designs have evolved, changes in systems and components have been made for the express purpose of reducing the vulnerability of these systems and components to damage from the threats expected to be encountered in combat. Examples of such changes are discussed in other sections of this report. These armor-protection features and systems-design changes should be described in detail in both operator and maintenance manuals for the aircraft. These manuals should explain why the more important measures have been taken and indicate that combat experience has formed the basis for the design decisions. Also, these manuals should emphasize the importance of combat data reporting for successes as well as failures. Such information in these manuals will serve several purposes. Stressing the incorporated survivability features of these aircraft based on combat experience should give added confidence to combat aircrews and reduce the possibilities of overloaded aircraft by the use of improvised armor. An understanding of survivability design features and knowledge concerning why the measures were taken may serve to deter aircrews and maintenance personnel from tampering in the field with these carefully designed features. Thus, the information in the manuals should augment a carefully planned training program for thorough indoctrination of all involved Army personnel in the most effective maintenance and utilization of the aircraft in the intended configuration for reduced vulnerability and enhanced survivability in combat.

c. Interrelationships between the aircraft hardware and operation of the aircraft as they pertain to the survivability of the aircraft and the safety of the crew should be stressed in the operator manuals. For example, the pilot should know how long the aircraft can fly after loss of transmission or engine oil. In an area with heavy enemy ground fire, aircrews have often landed aircraft immediately when loss of transmission or engine oil was indicated, and many aircraft have been lost due to landing in enemy-controlled areas. In some instances, those aircraft might have been saved had they flown further to land in a more hospitable area. Thus, it is important that the operator manuals indicate the time safety factor for continued flying after severe damage which causes loss of transmission or engine oil. Again, information in the manual would back up an intensive training program for aircrews in the proper procedures for maximum survivability of the aircraft after damage is incurred.

d. Information concerning successful emergency procedures based on the experience of combat pilots and documented in combat damage reports generally confirms the standard operating procedures outlined in the operator manuals. For example, the emergency procedures outlined in these manuals for the course of action to be followed when loss of anti-torque control occurs on helicopters equipped with tail rotors have been sustained by the combat data available on these aircraft. Anti-torque control loss arises when the tail rotor is in any manner impaired (loss of tail rotor controls, loss of tail rotor drive, loss of tail rotor either wholly or partially, loss of tail boom) or

fails to function properly. When this event occurs, it has been found that, depending on aircraft disposition, only two procedures are useful to land the aircraft safely. If the aircraft is in forward flight, the operator manuals suggest that the best procedure is a running landing. However, if this problem occurs while the aircraft is at sufficient altitude in hover or in some flight regime with small forward velocity, circumstances generally do not permit gaining enough speed to make a running landing. In this event, the recommended procedure is to enter autorotation immediately. Combat damage reports (References 12, 13, and 14) discuss loss or impairment of anti-torque controls at length and report the details of incidents involving this problem. Symptomatic and response characteristics of some damaged aircraft are also reported. These reports tend to confirm the established procedures for this type of emergency. Operator manuals for future helicopters with tail rotor installations should include statements in the emergency procedures section which indicate that combat experience supports these emergency measures. If additional combat damage data analyses reveal any changes that should be considered in aircraft operational procedures, these should be documented in the operator manuals.

e. Information derived from combat damage will be utilized in operator manuals such as those proposed for the UTTAS aircraft. These improved manuals, together with effective training programs for aircrews and maintenance personnel which include specific information concerning the survivability features of this and other aircraft and operational information for maximizing the survivability of the aircraft, should serve to minimize future aircraft losses in combat. Furthermore, these measures should stimulate thinking on the part of aircrew and maintenance personnel in the field concerning any hardware matters or operational procedures which might enhance aircraft survivability.

6-2. THE SINGLE PILOT PROBLEM IN OBSERVATION HELICOPTERS

a. An important problem that may be addressed or re-addressed by military operations planners at the decision-making level concerns the use of a single pilot in missions performed by observation helicopters. No data other than combat damage data shed specific light on this issue and spotlight the consequences in terms of lives saved or lost. Ordinarily, observation helicopters perform reconnaissance and scouting missions with a single pilot and a trained observer, only the pilot is qualified to fly the aircraft. Combat damage analysts have uncovered serious problems concerning this philosophy of combat operation.

b. Combat damage has underlined the aircraft loss rate due to single-pilot casualties and has stressed the need for at least some emergency training for observers or other personnel on aircraft that usually fly with a single pilot. The training need not be extensive, but some fundamentals necessary to safely land the aircraft would be highly desirable. Better aircraft survivability and mission performance would be assured if two qualified pilots are assigned to the mission of LOH aircraft. The second pilot should be trained primarily as an observer but should also be given sufficient training to have a capability for bringing the craft home safely if the primary pilot is in any way incapacitated. The thrust of the combat damage data concerning LOH aircraft strongly emphasizes that these aircraft should not be sent into combat again with only a single qualified pilot or a single set of flight controls.

6-3. CASUALTY REPORTS

One of the larger payoffs of combat damage analysis has come from an investigation into the primary kinds of casualties and the leading causes of these casualties for personnel aboard aircraft involved in adverse reactions. The findings in this area are of a dramatic nature for they deal directly with people and the saving of lives. Because of this, casualty reports tend to gain attention more rapidly than other combat-damage-oriented reports. The primary report published in this area is BRLM 2030 (Reference 1), which covered the time period 1962 through 1967. A second report is in preparation and will cover the time period 1968 through 1970. Casualty reports have stressed the need for armor and have analyzed the effectiveness of armor.

6-4. GUIDANCE OFFERED BY COMBAT DAMAGE ANALYSIS FOR SOLUTION OF SUSPECTED AIRCRAFT SURVIVABILITY PROBLEMS

a. Wounding from spall was considered to be a serious problem for aircrew members prior to publication of combat damage casualty reports. This problem is addressed in BRLM 2030; conclusions are reached based on the data analyzed that: (1) wounds from spall may largely be prevented by lightweight nonarmor materials and (2) extensive armorplating with attendant weight penalties to prevent spall effects is unnecessary.

b. The aforementioned casualty report, BRLM 2030, also addresses the problem of head and neck wounds among aircrew members. The data indicate that wounds in this area of the body were a major cause of combat fatalities of aircrew members. A protective helmet for the head and

neck is indicated by the study. However, the data also show many injuries to the head and neck from crashes. Any additional weight carried on the head in the form of a helmet to reduce wound casualties might add to the hazard of head and neck injuries in crashes. The net gain in lives saved by the use of ballistic helmets, even with a lightweight helmet designed for use against .30 caliber ammunition, is questionable. Detailed analyses of the survival of crew members in crashes should precede any decisions on this matter.

c. The analysis of combat data has also shown that a suspected fire hazard in hydraulic systems on Army helicopters has not posed a critical problem for helicopter systems to date. (However, hydraulic fires have been a problem in fixed-wing aircraft and may be anticipated in future helicopters with more complex and higher pressure systems.)

6-5. CONTRIBUTIONS TO MISSION ABORT ANALYSIS

Further combat damage analysis will lead to a better understanding of mission aborts. The analysis of causes of mission aborts will increase the chances for mission success. An exhaustive study of this problem has not yet been attempted, and it is recommended that this study be undertaken in the future. Only combat damage data can shed light on this problem. The analysis of this problem will not be considered credible unless the results are supported by combat damage data. It appears that the most frequent cause of mission aborts is casualties, while another important cause is intense fire in the landing zone. However, precautionary mission aborts occur frequently also. This type of mission abort should be studied closely to see if some procedure may be established to guarantee mission success more often and prevent costly, often unnecessary, mission aborts.

6-6. CONTRIBUTIONS TO AIRCRAFT MANUFACTURERS

Proper analysis of combat damage data requires a large data collection. This pool of useful and, in many cases, coordinated data has been used by a wider audience than the Department of Defense. Aircraft manufacturers have often contributed to and have received from the combat damage data bank pertinent information for studying the toughness of various aircraft systems. In this manner, the combat damage data collection and analysis program has helped to maintain a dialogue with aircraft manufacturers. Continued cooperation between AMSAA/BRL personnel and representatives of aircraft manufacturing companies in these areas should be fostered.

SECTION VII – THE APPLICATION OF COMBAT DATA TO PREDICTIVE TECHNIQUES

7-1. An important purpose of the combat data analyses is to provide verification or improvement of basic assumptions which must be made for many predictive vulnerability and effectiveness studies. This application of the combat data remains largely to be exploited since the primary emphasis has been placed on data collection, organization of the data, and direct reduction of aircraft vulnerability through protection or redesign of aircraft systems. Some preliminary investigations which were directed toward the verification of predictive vulnerability methods have been made.

7-2. Vulnerability analysis and the studies which they support (e.g., survivability, attrition, effectiveness, cost effectiveness, operations) require selection of certain kill or defeat categories for evaluation. Attrition and forced-landing damage categories have been investigated mainly in the past. Significant efforts are now in process to make evaluations in categories of mission abort and mission availability as they relate to repair time. To accomplish these studies, criteria of damage levels to the aircraft or crew members for a kill in a damage category are established for each aircraft study. Information obtained in analysis of combat damage data has often been utilized in establishing these criteria. Among the significant findings from the analyses of combat damage data which have a strong bearing on these kill criteria are those concerning *redundant* systems of aircraft. In some aircraft, the combat damage data strongly suggest that some of these systems are not actually redundant under a wide spectrum of conditions. (For example, see Section V for a discussion of the dual engine system.) Furthermore, the combat data show examples where helicopter crashes occur after a pilot is wounded or killed when the aircraft is in a critical maneuver in spite of the presence of a second pilot with dual controls available. Additional study of the combat data is needed that is directed toward a better understanding of the response of redundant systems of aircraft to damage to part of the system and the reactions of pilots under a variety of conditions.

7-3. In analytical studies of weapons effectiveness, the availability of rotary-wing aircraft for future operations after being forced to make a landing as a result of enemy action has generally been based on an assumed recovery rate. An examination of the combat damage data for either all Army helicopters or all helicopters covered in this summary shows that a larger percentage of the aircraft forced to land were recovered. It should be noted that most analytical studies have assumed a mid-intensity ground threat environment, whereas most action in Vietnam involved a low-intensity ground threat environment. Further information concerning the expected recovery rates for downed aircraft under various conditions could probably be obtained from additional analysis of the available data.

7-4. The combat damage data bank should be searched for additional information which may shed light on the causes of mission aborts (e.g., relationship of mission abort incidents to flight conditions – altitude, speed, mission types, flight phase, time of day). In particular, since many effectiveness and survivability studies involve attack helicopters, there is a need for an in-depth examination of all available data for UH-1B/C and AH-1G helicopters to determine the engagement conditions and/or the level of damage to the aircraft or crew which result in the premature termination of the mission of these aircraft in attack on ground targets.

7-5. In summary, limited verification of some of the predictive techniques and basic assumptions germane to analytical studies have been provided by the analysis of aircraft combat damage data to date. The combat damage data present ideal opportunities to challenge and improve the existing predictive techniques for aircraft vulnerability and survivability.

SECTION VIII – APPLICATIONS OF COMBAT DAMAGE ANALYSIS TO FUTURE AIRCRAFT

8-1. The ultimate value of combat damage analysis lies in its application to the vulnerability reduction of future aircraft. It is here that combat damage analysis can bring to bear all of the experience gathered from years of effort and investigation and make a significant contribution to the survivability of aircraft in a combat environment. Of paramount interest in these considerations is the fact that government project managers and aircraft manufacturers' representatives listen with greater attention when confronted with the facts and figures accrued by combat damage analysis supporting survivability measures. It is difficult to deny the results of combat experiences, particularly if these are well documented. The various agencies of the Department of Defense involved with the procurement of aircraft and responsible for creating the guidelines and specifications of new aircraft welcome the opportunity to employ the valuable lessons learned from analysis of combat damage data. Combat damage analysts have contributed, and are now contributing, to the requirements and specifications of new aircraft with the intent of correcting, modifying, and suggesting engineering guidelines for the vulnerability reduction of these proposed aircraft. Specifically, combat damage reports devoted to the UH-1 aircraft furnished data for the UTTAS helicopter specifications. Similarly, analyses concerned with the AH-1G aircraft supported the design specifications established for the AAH helicopter. The CH-54, CH-53, CH-47, and CH-46 reports have supplied relevant data incorporated into the design features of the HLH helicopter. Further, the ARH aerial reconnaissance helicopter will have specifications modified to reflect lessons learned for this type of aircraft from OH-13S/23G, OH-6, and OH-58 combat experiences as presented in the respective combat damage reports.

8-2. As an example of the type of influence that combat damage analysis has on the design criteria of impending aircraft, it may be noted that some of the recent request for quotation (RFQ) requirements were adopted because of specific lessons learned through combat damage analysis while others were adopted just because of improved receptiveness following Southeast Asian experiences.

8-3. For the UTTAS helicopter and its T700 e[illegible] vulnerability reduction and survivability were among [illegible] factors considered and weighted in the evaluation for source selection of this design helicopter. Numerous request for proposal (RFP) requirements were incorporated specifically to reduce vulnerability to ground fire. Initial vulnerability assessments were required to accompany the proposed designs, and prototype hardware and test beds are to undergo vulnerability tests by various Department of Defense agencies. Concurrent with the development efforts, a Survivability/Vulnerability Plan requirement assures that vulnerability will be minimized through continuing contractor evaluation and trade-off analyses of design changes, guided by ad hoc testing of material samples, mockups, and high-time or expended components by the contractor or by proper government agencies, as appropriate.

SECTION IX — SPECIFIC AREAS FOR FUTURE APPLICATIONS

9-1. GENERAL

a. This section will outline some of the problem areas in which future combat data analyses should be accomplished to provide necessary insights toward solutions. As emphasized throughout this report, the most obvious and also the most important applications of the results of analyses of aircraft combat damage data are in the general reduction of the vulnerability of aircraft and the reduction of casualties among airborne personnel. However, other information is contained among these data which may be of value in the planning of future combat operations involving aircraft. Some specific recommendations for further analyses of these data will be offered. Some of these recommendations have appeared in earlier sections of this report but will be enumerated again in this section.

b. At this point, before any specific recommendations are made, it should be noted that in many cases it is difficult to determine the precise degree to which the combat damage data influenced government and industry vulnerability reduction specialists. In some cases, it is likely that the specialists, pursuing an idea, sought confirmation in the combat data. In other cases, it is likely that the combat data ignited the spark which produced an investigation that resulted in vulnerability reduction or merely a lesson learned. This may be particularly true since vulnerability reduction specialists have also been involved with the analysis of combat damage data for a number of the aircraft. Which came first is not really important, but what is important is that this data bank, accumulated over a 10-year period, be available in the future to the vulnerability analyst for use as his needs dictate.

c. Combat damage data are not a substitute for controlled vulnerability testing, but they are a required supplement. For certain types of damage which can be readily simulated by proving ground tests, additional questions must be asked. Given a specific damage to aircraft systems in flight, could a given aircraft continue to fly? If so, for how long? If it could, would pilots normally try? Can the mission of the aircraft be completed? Answers to these questions can sometimes be as important as the observations made from ground tests. Such answers cannot be obtained except from combat damage statistics. Vulnerability analysts who are actively involved in firing tests, and others, should be given the opportunity to specify the type of information required concerning aircraft response to specific damage to supplement and increase their experience. The statistical base is large enough now to produce, for example, detailed analyses of specific aircraft systems to determine relative hardness (or softness) of these various systems.

9-2. SUPPORT OF NEW AIRCRAFT DEVELOPMENT

a. The most pressing need for the combat data analyses is for the support of survivability requirements in the procurement of the next generation aircraft. Of principal concern are the AAH, HLH, and UTTAS.

(1) Advanced Attack Helicopter (AAH). To date, about half of the reported AH-1G combat damage incidents has been analyzed. The remaining data should be analyzed in context with the previous reports (References 15 and 16).

(2) Heavy-Lift Helicopter (HLH). Analyses on 33 percent of the reported incidents of combat damage on CH-47 and CH-54 helicopters have been completed. All remaining incidents should be analyzed. In addition, all data on large non-Army helicopters (CH-3, CH-53, CH-46) should also be analyzed for guidance in HLH survivability requirements.

(3) Utility Tactical Transport Aerial System (UTTAS). A large sample of combat damage incidents on UH-1 helicopters has been reported. Only 22 percent of these incidents has been analyzed. Selective studies should be conducted to exploit these data in support of the UTTAS development and its significant survivability requirements.

b. The OV-1 is the largest fixed-wing aircraft, in the U. S. Army inventory, which operated in Vietnam. Data on combat damage through June 1967 have been analyzed and published. Since this aircraft with its mission of reconnaissance operated along the border, it was subjected more often to large threats (.50 caliber to 23mm). In addition, problem areas uncovered in the first analysis and the recommended fixes should be investigated in the remaining data. Such analysis should also benefit any future Army aircraft for this mission.

9-3. MULTIPLE SYSTEMS DAMAGE

There are many instances in the combat damage reports where adverse aircraft reactions were brought about by damage to multiple systems of the aircraft. This damage was caused by either multiple hits with several rounds or single rounds impacting on components of several systems. In some cases, it was possible to identify the one system which was the most likely cause of the aircraft reaction; however, in many cases, this was not possible. There is a need for better understanding of the multiple-hit damage phenomenon and its influence on vulnerability reduction as well as mission accomplishment. An analysis of data available in the combat damage data bank concerning multiple hit damage to various aircraft would provide insight concerning this phenomenon and, from a hardware point of view, offer some information on spacing of redundant components and help identify systems for which simultaneous damage results in synergistic effects. Of particular interest in this area would be the interaction of pilot/copilot wounding with other simultaneous systems damage.

9-4. COMPARISON OF DAMAGE EFFECTS TO FUNCTIONAL AIRCRAFT SUBSYSTEMS

a. Studies of systems damage and effects must be continued to compare the vulnerability of different systems and their components designed for the same function in different aircraft, or different designs for the same aircraft. For instance, data suggest that the rotor system of one helicopter is more vulnerable than rotor systems of other aircraft. More detailed investigations should be undertaken to verify and understand such observations.

b. Additional analyses are needed to compare the relative merits of the flight controls systems and components in the various aircraft. How do the different push-pull rods, torque tubes, bellcranks, cables, cable pulleys, and other mechanical control components employed in various aircraft compare in ballistic tolerance? What are the critical parameters of hydraulic systems that can contribute to serious hydraulic fires? Similar detail is also needed to understand the variety of fuel and lubricating oil fires that may occur on an aircraft in flight. Power-train vulnerability results directly from damage to bearings, gears, and shafts, and also indirectly to oil starvation; the damage reaction of such components is highly influenced by difference in design detail.

9-5. INVESTIGATION OF MISSION ABORTS

For the next generation of Army helicopters (UTTAS, HLH, AAH), a considerable effort has already been expended toward vulnerability reduction in the attrition and forced-landing categories. Success in vulnerability reduction in these two serious damage categories should stimulate an increase of attention to the mission abort category of damage. The combat damage data should be investigated to determine the principal causes of aborted missions in order that vulnerability reduction techniques may be applied to this class of damage. Changes in operational procedures could also increase the probability of mission completion. Many mission aborts were precautionary in nature, and the findings of combat damage analyses incorporated in the pilots' operator manual, as previously discussed, could result in a reduction of this type of reaction on the part of the pilots. Pilots in a combat environment must make quick and critical judgments when damage occurs; any information which can be gleaned from the combat damage data bank which could aid in these judgments should be made available to them both in the form of manuals and incorporated in the training program.

9-6. REPAIRABILITY AND REPAIR TIME

Although extensive research has been conducted to minimize repair time in normal aircraft maintenance, practically no consideration has been given to repairability of combat damage, major or minor. Since most of the aircraft hit by ground fire did continue to fly, an extensive variety of damage has been observed which should be analyzed to glean desirable (and to identify undersirable) design features.

9-7. SAFETY IMPLICATIONS (NONHOSTILE ACCIDENTS)

Whereas the primary purpose of combat damage analysis is to improve combat survivability, benefits might accrue to aircraft operating in nonhostile environments. The fundamental causes of a crash, for example, are the same for aircraft operating in hostile and in nonhostile environments. An oil leak results in an oil-starved bearing whether the oil line is severed by a bullet or a fitting fails. During hostilities, combat damage occurs more frequently than materiel failures; hence, the combat data can add significantly to the accident experience statistics. Since the data have already been collected, it is only necessary to analyze such data from a different point of view.

9-8. RECOMMENDATIONS

The above discussion has outlined a few of the problems where combat damage data analyses may provide insights toward solutions. The efforts made by AMSAA/BRL should be continued somewhere in the DOD community. A special team should be trained, ready for deployment whenever and wherever opportunities develop to collect combat damage data.

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